UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

AD-A205 146

(1)

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION: UNCLASSIFIED	1b. RESTRICTIVE MARKINGS
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: APPROVED FOR PUBLIC RELEASE DISTRIBUTION IS UNLIMITED
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)	5. MONITORING ORGANIZATION REPORT NUMBER(S): AFOSR-TR- 89-0133
6a. NAME OF PERFORMING ORGANIZATION: UNIVERSITY OF WASHINGTON; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: AFOSR/NA
6c. ADDRESS (City, State, and ZIP Code): DEPT APPLIED MATHEMATICS SEATTLE, WASHINGTON 98195	7b. ADDRESS (City, State, and ZIP Code): BUILDING 410 BOLLING AFB, DC 20332-6448
8a. NAME OF FUNDING/SPONSORING ORGANIZATION: AFOSR; 8b. OFFICE SYMBOL (If applicable): NA	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: AFOSR-84-0111
8c. ADDRESS (City, State, and ZIP Code): BUILDING 410 BOLLING AFB, DC 20332-6448	10. SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO. 61102F; PROJECT NO. 2307; TASK NO. A4; WORK UNIT ACCESSION NO.

11. TITLE (Include Security Classification)

(U) DEVELOPMENT OF A STREAMLINE METHOD

12. PERSONAL AUTHOR(S)

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13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
FINAL	FROM 1 Jun 87 TO 31 AUG 88	NOV 1988	2

16. SUPPLEMENTARY NOTATION

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	COMPUTATIONAL AERODYNAMICS, AXIAL FLOWS. (mgm)

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The research investigated and developed a novel streamline method for the computation of steady state compressible flows in ducts and axial compressors. The method is based on the discription of a streamline in terms of axial position and two parameters. A coupled pair of second order differential equations are developed and solved by a relaxing process in the subsonic case and by downstream marching in the supersonic case.

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20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION: UNCLASSIFIED
22a. NAME OF RESPONSIBLE INDIVIDUAL: HENRY E. HELIN	22b. TELEPHONE (Include Area Code): 202-767-0471; 22c. OFFICE SYMBOL: AFOSR/NA

DD Form 1473, JUN 86 — Previous editions are obsolete. — SECURITY CLASSIFICATION OF THIS PAGE

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AFOSR-TR- 89-0133

Final Technical Report: Attn Capt H. Helin
AFOSR-84-0111
Development of a Streamline Method

Principal Investigator: Professor Carl E. Pearson
Department of Applied Mathematics
University of Washington, Seattle, WA

The purpose of this research was to further develop and investigate a novel streamline method for the computation of steady state compressible flow in ducts and axial compressors. The method is based on the description of a streamline in terms of axial position and (in three dimensions) two parameters; the existence of a conventional stream function is not necessary. Initially, it was planned to iterate the streamline positions so as to satisfy the Euler equations; it later turned out to be more efficient to obtain a coupled pair of second-order partial differential equations governing the stream positions, and to solve those equations by a relaxation process in the subsonic case and by downstream marching in the supersonic case.

The coupled pair of equations described above are quasilinear, and elliptic or hyperbolic in nature depending on whether the flow is subsonic or supersonic. They are of considerable mathematical interest in themselves, since they represent a new formulation of the Euler equations of fluid mechanics. It also turns out that they are computationally very efficient in appropriate problems; timing tests show a speed gain, as compound as conventional CFD methods, ranging from a factor of 2 to a factor of 20.

The method has been applied to a prototype axial compressor problem, and compared to existing solutions for accuracy and speed. A large number of duct flow problems (some with free surfaces) have also been solved, including some fully 3-dimensional ones. Purely subsonic or purely supersonic problems can be solved very effectively by the present method; as with all CFD steady-state methods, problems involving both subsonic and supersonic flow require matching at the interface. For the present method, an appropriate matching technique has been developed and found to be reasonably successful. One result of some interest is the relative insensitivity of the upstream or downstream flow to small changes in the transition region (e.g., in the location of the $M = 1$ surface).

For swirling axially-symmetric flow, the method accurately reproduces the known structure of the mathematical problem — thus relaxation continues to converge as long as the axial Mach number is less than one, even if the flow is locally supersonic.

To a limited extent, the method is able to handle shock waves, despite the fact that the equations are not formally of conservation form. Thus the shock location and strength were found to be accurately given by the method for the classical problem of supersonic flow against a wedge.

A matter of considerable mathematical interest concerns the boundary conditions to be used in 3-dimensional solutions of the coupled pair of second-order equations previously described. Mathematically, it would appear that more boundary conditions are necessary than those physically available; it turns out however that the problem is very insensitive to these additional boundary conditions, the effects of which die out within pseudo boundary layers.

Two doctoral theses have dealt with selected topics under this research program. The students were Jeffrey Q. Cordova (now at NASA Ames) and D. Richard Owens (now at Aerospace Corporation).

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A paper by Carl Pearson, describing some early results, appeared in Comm. Appl. Num. Meth. 1, 1985, p. 177–181: "Extension of a Numerical Streamline Method". In an invited lecture to the March 1987 Texas Workshop on Numerical Analysis, Pearson described some results obtained by Cordova and Pearson; this joint paper, "On a Modified Streamline Curvature Method for the Euler Equations" appeared in Comm. Appl. Num. Meth. 4, 1988, p. 327–333. Finally, a joint paper by Owen and Pearson was presented at the AIAA 26th Aerospace Sciences meeting, January 11–14, 1988, Reno, Nevada as AIAA-88-0625: "Numerical Solution of a Class of Steady-State Euler Equations by a Modified Streamline Method".

These 3 papers, together with the theses by Cordova and Owen (available from Ann Arbor Microfilms), constitute the main technical portion of this final report. Copies of the papers are attached.

To conclude, we believe that this has been a very successful project. A novel formulation of the Euler equations of fluid mechanics has been found to lead to a very effective approach for certain CFD problems of practical interest. Future work might be directed toward external flow and toward the inclusion of viscous effects.

At this point, the researchers would like to express their appreciation to AFOSR for its support of this project; we hope that AFOSR is as pleased with the results as we are.

Signed: ______________________

Carl E. Pearson
Principal Investigator

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